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DEPARTMENT OF DEFENCE  
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION  
SURVEILLANCE RESEARCH LABORATORY  
SALISBURY, SOUTH AUSTRALIA

TECHNICAL MEMORANDUM  
SRL-0027-TM

A TECHNIQUE FOR THE GENERATION OF RANGE-HEIGHT-ANGLE CHARTS

J.L. WHITROW and J.A. DOIG

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J.L. WHITROW and J.A. DOUG

S U M M A R Y

This memorandum discusses a technique for the computer generation of range-height-angle coverage charts for radars of arbitrary height. Such charts are useful to provide a qualitative assessment of propagation paths between a radar and an arbitrarily positioned target.

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## 1. INTRODUCTION

This report describes a software package for the generation of range-height-angle charts, which are commonly used to provide qualitative guidance on the propagation characteristics of electromagnetic waves through the atmosphere in the solution of radar and communication problems. Such charts show the interrelationship between range to a target, the height of the target, and the angle that a ray has to be launched from the source to reach the target position. They may appear in many forms, but most often have, and are most useful when, the range and height axes are transformed so that the propagation paths are straight lines. The need for such charts arises because within the atmosphere the paths are governed by the spatial variation of the atmospheric refractive index, and are generally curved downwards due to the normal reduction in refractive index with height. Under more extreme circumstances this curvature can match the curvature of the Earth, and consequently the radar waves can propagate considerably beyond the geometric horizon, a condition known as ducting. Thus, most often, given a specified target position and a radar position, it is not immediately apparent if a propagation path exists between them for a particular atmospheric refractive index profile. Nor is it simple to deduce the launch angle of the ray from the radar that passes through the target position, and it is in answer to such questions that range-height-angle charts are commonly constructed.

Most charts that have been published to date(ref.1,2) usually assume a standard atmospheric refractive index profile(ref.5), and place the source at ground level. Although it is possible to deduce if a ray path exists between two elevated points by determining separately the horizon distance of each of the points and comparing the sum of these with the physical separation of the points, the launch and arrival angles of the ray between the points cannot be determined in this process. The alternative of providing an extensive set of charts covering the range of source heights of interest, typically from 0 to 100,000 ft for most aircraft applications, and for various refractive index profiles is not particularly attractive, but with the advent of high speed digital computers with good graphics capabilities, it is possible to generate charts simply for each specific situation of interest. This report details a software package that has been developed for this purpose by adapting a general purpose program for tracing rays through the atmosphere(ref.4) that was written for use with a radar system modelling package under development in Microwave Radar Division. Reference 3 details an alternative method for the generation of charts for elevated sources, with a standard exponential reference atmosphere. The charts presented therein have the angular ordinate scaled by a factor of 10, giving them an unusual form and restricting the coverage of high and low aspect angles. No such limitations exist with our product.

The software program that has been developed is completely general, in that the user specifies the source height, the limits in range and height to which the rays are to be traced, and the functional form of the atmospheric refractive index profile. The output of the program is a range-height-angle chart, in which, by appropriate transformations of the range and height axes, the ray path from the radar is depicted as a straight line. Previously published charts have commonly depicted ray path length as the range parameter, resulting in portions of ellipses for the constant range curves at short range. We have however chosen to use ground range as the range parameter, resulting in a slightly different form for the constant range curves as we have found this to be more useful for our purposes. At moderate range the differences are only slight, but for specific requirements where the differences are significant, it would be straightforward to adapt the software to use the ray path length as the range parameter.

## 2. THEORY

### 2.1 Ray tracing through the atmosphere

The fundamental requirement in the generation of range height angle charts is to be able to trace the path of rays as they propagate through the atmosphere. In this work we will rely upon the techniques of geometrical optics for this task, noting as an aside that such techniques will be inadequate at and near caustics of the rays, but also observing that this package is not intended to be used for refractive index profiles which give rise to such phenomena. The theoretical basis for ray tracing is treated more fully elsewhere(ref.4), but may be summarized for our purposes as follows.

- (1) At any point in the (horizontally stratified) atmosphere, the local curvature,  $K$ , of a ray will be

$$K = -\frac{1}{n} \cos \alpha \frac{\partial n}{\partial z}$$

where  $\alpha$  is the angle of the ray to the horizontal, and  $n$  is the atmospheric refractive index.

- (2) Assuming that the curvature of the ray is constant along a sufficiently small segment of the ray path (say 100 m for example), then the coordinates of the end point of the segment may be simply determined from the coordinates of the start of the segment (see figure 1): thus compute

$$(a) \Delta\tau = K\Delta S$$

$$(b) \Delta L = \frac{2}{K} \sin \left\{ \frac{\Delta\tau}{2} \right\}$$

$$(c) \sigma_i = \frac{1}{2} (\pi - \Delta\tau)$$

$$(d) h_{i+1} + R = \left\{ (h_i + R)^2 + \Delta L^2 - 2(h_i + R) \Delta L \cos (\alpha_i + \sigma_i) \right\}^{\frac{1}{2}}$$

$$(e) \Delta\theta_i = \arcsin \left\{ \sin (\alpha_i + \sigma_i) \frac{\Delta L}{h_i + R} \right\}$$

$$(f) \alpha_{i+1} = \alpha_i + \Delta\theta_i - \Delta\tau$$

where  $(h_i, \theta_i)$  defines the height above the surface of the Earth and the angular position based on the centre of the Earth of the start of the  $i^{\text{th}}$  segment, and  $(h_{i+1}, \theta_{i+1})$  the same parameters at the end of the  $i^{\text{th}}$  segment, ie the start of the  $i+1^{\text{th}}$  segment. The angle  $\alpha$  in these expressions is the angle of the ray to the local horizontal to the Earth's surface, and  $R$  is the radius of the Earth. Figure 1 illustrates the relationship between these parameters.

(3) Using the above procedure iteratively, rays can be launched from the source and traced until either the range or height exceeds the boundaries specified for the chart, or the ray intersects the surface of the Earth.

## 2.2 Intersection of a ray with a constant height curve

To construct the constant height curves of the chart, we need to determine the points on each of the rays at which the heights of the curves are crossed. The problem is very similar to that of tracing the rays outlined in the previous section, except that in this case, we know the final height of the end point of the segment but not the segment length. Assuming that the  $i^{\text{th}}$  ray path segment straddles the height,  $H$  for which a curve is required, then on referring to figure 1, in which  $h_{i+1}$  is replaced by  $H$ , and putting

$$Z_i = h_i + R$$

$$Z = H + R$$

it can be shown that

$$Z^2 = Z_1^2 + \Delta L^2 + 2Z_1\Delta L \sin\left\{\alpha_1 - \frac{\Delta\tau}{2}\right\}$$

On expanding the trigonometric function, and noting that

$$\Delta L = \frac{2 \sin(\Delta\tau/2)}{K}$$

where  $K$  is the curvature of the ray, a quadratic in  $\Delta L^2$  which can easily be solved, is obtained. The form is

$$A \Delta L^4 + B \Delta L^2 + C = 0$$

in which

$$A = (KZ_1)^2 - 2KZ_1 + 1$$

$$B = 2 \left\{ (Z^2 - Z_1^2)(KZ_1 \cos \alpha_1 - 1) - 2Z_1^2 \sin^2 \alpha_1 \right\}$$

and

$$C = \left\{ Z^2 - Z_1^2 \right\}^2$$

There are two positive real solutions to this equation, of which the one we seek can be shown by geometrical construction to be the smaller. The problem of whether a real solution exists does not arise since the procedure is invoked only for segments which straddle the specified height curves. After solving for  $\Delta L$ , the arc length  $\Delta S$  can be determined, and from this, the ray path length to, and the coordinates of, the intersection point on the chart may be calculated.

### 2.3 Intersection of a ray with a constant range curve

The intersection point of a ray with a particular range curve follows in a similar fashion. Referring again to figure 1, and assuming that the  $i^{\text{th}}$  segment of the ray path crosses the range curve, then since we know  $\Delta\theta_i$  from the range and since

$$\Delta\tau = 2 \arcsin \left\{ \frac{\Delta L}{2} K_i \right\}$$

on applying the sine law for the ratio of sides of a triangle, we obtain the result

$$\begin{aligned}\frac{\Delta L}{\sin(\Delta\theta_1)} &= \frac{Z_1}{\sin \gamma} \\ &= \frac{Z_1}{\cos(\Delta\theta_1 + \alpha_1 + \tau/2)}\end{aligned}$$

A quadratic for  $\Delta L^2$  similar to the previous case can then be deduced in which the parameters A, B, and C assume the values

$$A = \frac{1}{4} K^2$$

$$B = -Z_1 \sin \theta_1 \sin(\theta_1 + \alpha_1) K - \cos^2(\theta_1 + \alpha_1)$$

$$C = Z_1^2 \sin^2 \theta_1$$

Once  $\Delta L$  is determined,  $\Delta\tau$  follows, and from it, the path length along the arc to the intersection point of the ray path with the specific range curve, and the height of the intersection point may be calculated.

#### 2.4 Construction of range-height-angle charts

A range height chart may be constructed by tracing the paths of a set of rays launched at various angles from the source, and generating tables of the path lengths of the rays to the intersection points of the rays with the heights and ranges for which curves are required. The loci of the points of constant height and constant generated by the set of rays provide a variable scale for the axes, whereby the ray paths may be drawn as straight lines. The procedure for the generation of the range and height contour intersection points for each ray is terminated when the end point of a ray segment exceeds either the maximum height or the maximum range specification or intersects the surface of the Earth. To provide an accurate boundary for the chart, the end point of the last segment is adjusted to terminate precisely on the height or range boundary, using a variation of the procedures described in Sections 2.3 and 2.4 in which all the parameters of the end point of the increment are revised once the step increment  $\Delta L$  is known. For each intersection point, the mapping used to determine the location on the chart  $(X_p, Y_p)$  with respect to the chart origin is:

$$X_p = R_p \cos \alpha / X_s$$

$$Y_p = (R_p \sin \alpha + H_s) / Y_s$$

where

$R_p$  is the total ray path length to the intersection point

$\alpha$  is the launch angle of the ray from the source

$H_s$  is the height of the source above the surface of the Earth

$X_s, Y_s$  are the x and y axis scale parameters

Determination of the scale factors will be discussed later.

Given then, the points on the chart at which the rays intersect each of the specified heights and ranges, the curves for constant height and range can be constructed by connecting the respective points. Since the rays are traced at various starting angles from the source, beginning at  $+90^\circ$  and extending through  $0^\circ$  to  $-90^\circ$ , it does not follow that the points of the height and range curves are generated in sequential order: in particular for an elevated source height it is possible for rays launched below  $0^\circ$  to cross particular height boundaries twice provided that they do not first intersect the surface of the Earth. Connection of the points of each curve in the order of their generation would not provide a monotonic result. This problem has been resolved in the software by sorting the points for each height curve and for each range curve, into increasing range and height order respectively before plotting.

The upper boundary of the chart is formed by the rays which terminate at the height limit, the right hand side by the rays that terminate at the range limit, and the bottom by the rays which terminate on the surface of the Earth and by the extension of the tangent ray. Certain pathological conditions, for example only having one ray terminating on the right hand boundary, are taken care of by making assumptions about the shape of the curve where greater detail is not available. In the quoted example, the right hand boundary is assumed to be vertical. Where there are no rays terminating on the maximum range boundary, the tangent ray and the maximum height boundary intersect each other. Another problem that arises is that most often the points that define the intersection of each of the range curves with the maximum height boundary (and the complementary situation) will not be generated in the ray tracing: this problem has been resolved by linearly interpolating the respective curve data to provide the intersection point with the boundary. Provided that the successive rays are closely spaced (in chart coordinates), this gives an acceptably accurate result.

A major difficulty in developing the software was experienced in getting the rays suitably spaced to provide an adequate number of data points for each range and height curve for the expected practical values of the range and height limits. This problem has been resolved by determining approximately the launch angles from the source, of the ray that passes through the range height boundary intersection, and the ray tangent to the Earth's surface, using a

4/3<sup>rd</sup> Earth radius model. From the geometry of figure 2, it follows that the launch angle  $\rho$  to the range-height boundary intersection is:

$$\rho = \tan^{-1} \left\{ \frac{(R_{eff} + H_{max}) \cos \delta - H_s - R_{eff}}{(R_{eff} + H_{max}) \sin \delta} \right\}$$

where

$$\delta = \frac{R_{max}}{R_{eff}}$$

$R_{max}$  = maximum range of ray tracing

$R_{eff}$  = effective Earth's radius = 4/3 times actual Earth's radius

$H_s$  = source height

$H_{max}$  = maximum height of ray tracing

Similarly the launch angle  $\beta$  for the ray tangent to the Earth's surface is (from figure 2)

$$\beta = \cos^{-1} \left\{ \frac{R_{eff}}{H_s + R_{eff}} \right\}$$

and the angle  $\gamma$  to the bottom corner of the chart is

$$\gamma = \frac{H_s + (1 - \cos \delta) R_{eff}}{R_{eff} \sin \delta}$$

The software package then traces rays in various intervals (5°, 10° or 20°) from 0° to 10°, then in 0.5° intervals to  $\rho$ , 0.1° intervals to 0°, 0.02° intervals to  $\beta$ , 0.1° intervals to  $\gamma$ , 1° intervals to 10°, and various intervals to 90°. In fact this software is slightly more complicated than suggested above, based on the relative values of the break points for different angular steps, and the values of  $\beta$ ,  $\delta$  and  $\gamma$  (see Listing 2). However the general principles are adequately illustrated, with the finest division of launch angle being used between 0° and the ray tangent to the surface. In general the scheme has worked well, but for possibly extreme uses of this software in which the specified maximum height is very small with respect to the maximum range, the resulting charts may not have enough points to give an adequately smooth set of range and height curves. In such circumstances it will be necessary to modify the angular increments and break points to suit the requirement at hand.

The selection of the X and Y axis scale parameters and the position of the origin so that the chart occupies the entire output page is not straightforward. For charts with extended ranges (see for example figure 6) a considerable portion of the chart lies below the origin, and consequently the origin has to be raised (relative to the bottom of the chart) and the Y scale compressed to fit the chart in. In this package these parameters are determined using a 4/3<sup>rd</sup> Earth approximation to produce a chart 8" x 6" in dimensions, and then applied to the ray tracing output. Two situations are of significance in these calculations, whether the tangent ray to the surface of the Earth touches the surface before or after the maximum range.

If the maximum range is less than the tangent range, then, referring to figure 3(a), we compute.

$$\phi = \frac{R_{\max}}{R_{\text{eff}}}$$

from which the scale factors  $X_s$ ,  $Y_s$  follow immediately, thus

$$X_s = R_{\text{eff}} \sin \phi / X_L$$

$$Y_s = \left\{ H_{\max} + R_{\text{eff}} (1 - \cos \phi) \right\} / Y_L$$

where  $X_L$  and  $Y_L$  are the X and Y dimensions of the chart.

If the maximum range is greater than the tangent range, then determining the scale factors is a little more complicated. Referring to figure 3(b), we compute

$$\phi = \cos^{-1} \left\{ \frac{R_{\text{eff}}}{R_{\text{eff}} + H_s} \right\}$$

$$\psi = \frac{R_{\max} - R_t}{R_{\text{eff}}}$$

The height of the tangent ray above the surface of the Earth at range  $R_{\max}$  is

$$H_t = R_{\text{eff}} \frac{1 - \cos \psi}{\cos \psi}$$

If this height is greater than  $H_{\max}$ , then the angle  $\psi$  is revised so that the tangent ray terminates at maximum height, thus

$$\psi = \cos^{-1} \left\{ \frac{R_{eff}}{R_{eff} + H_{max}} \right\}$$

The scale factors for the axes thus become:

$$X_s = R_{eff} (\tan \phi + \tan \psi) \cos \phi X_L$$

and

$$Y_s = \left\{ H_{max} - H_s + R_{eff} (\tan \phi + \tan \psi) \sin \phi \right\} Y_L$$

The length of the vertical axis then follows:

$$L = H_{max} / Y_s$$

and from this the position of the origin may be determined so that the chart fits neatly on the output page. In our system, we use

$$X_o = 1.5$$

$$Y_o = 7.2 - L$$

which roughly centres the chart on an A4 page

### 3. INVOKING AND USING THE SOFTWARE

#### 3.1 User interface

The software described in this report is part of a larger package which can carry out a variety of ray tracking tasks on the IBM 370 system. The complete software for the package is contained in a variety of data sets beginning with the descriptors 'JLW RAYTRACE', the source code for the ray tracing and chart generation procedures is in 'JLW RAYTRACE PLI(MAIN3)', and other members of 'JLW RAYTRACE PLI' are called by MAIN3. The user interface is via SPE panels, invoked initially by the CLIST, 'JLW CLIST(RAYTRACE)'. This CLIST allocates the appropriate SPE menus and panels which run the ray tracing software, and then displays the first panel to select the ray tracing task required. The options available in this package at present are

- (1) trace rays from an antenna for an arbitrary refractive index profile
- (2) trace the ray paths between two points (suitable only for a refractive index profile which does not give rise to ducting)

- (3) plot range-height-angle charts
- (4) plot propagation loss between two points as a function of height of the receiver
- (5) generate resolution cells for time difference height finding for a 4/3<sup>rd</sup> or other effective radius atmospheric profile

In the case of the generation of range-height coverage diagrams, the third option should be selected, by entering the number 3 at the cursor OPTION prompt (the layout of the first panel is shown in figure 4), whereupon the panel requesting input of the parameters relevant to the generation of the range height charts will be displayed (figure 5). The parameters are self explanatory, with the exception of the procedure which describes the atmospheric refractive index profile: this is described in the next section. Selection of GDDM output will display the range height chart on the IBM terminal, and selection of HP output will produce Hewlett Packard graphics language (HPGL) instructions to drive a Hewlett Packard plotter to produce a hard copy of the chart, on the output file 'JLW.RAYTRACE.PIOT(name)'. These instructions may be subsequently downloaded to a HPGL compatible plotter to produce a hard copy of the range height chart. A help facility is available via the PF1 key (press once for short message, a second time for a detailed explanation) if the user is uncertain of the appropriate parameters to enter in any of the panel input fields.

### 3.2 The procedure specifying the refractive index profile

The RAYTRACE package contains a number of different procedures for calculating the refractive index of the atmosphere. At present only two, namely ATMOS1 and ATMOS2 which contain the NBS single term exponential and two term exponential profiles (ref. 5) are appropriate for use with this package. These profiles are respectively

$$n = 1 + 313.6 \times 10^{-6} e^{-(h/7000)}$$

and

$$n = 1 + 265.0 \times 10^{-6} e^{-(h/9000)} + 48 \times 10^{-6} e^{-(h/2500)}$$

where h is the height above the surface of the Earth in metres. The procedure ATMOS1 was used to generate the range-height chart examples in this report.

Any alternative refractive index profile may be used by developing another procedure to supply the refractive index as a function of height. The call to the procedure is of the form

```
CALL ATMOS (HEIGHT, ALPHAR, REFINX, SLOPE)
```

in which all the arguments are DECIMAL FLOAT (16) variables, (ie double precision). The input parameters to the procedure are

- (1) HEIGHT, the height of the point on the ray above the surface of the Earth (metres), and
- (2) ALPHAR, the angle of propagation of the ray with respect to the local horizontal (radians).

For refractive index profiles which do not contain any discontinuities (such as ATMOS1 and ATMOS2) the parameter ALPHAR is not used, but is included in the CALL to provide compatibility with other refractive index procedures. The procedure then returns

- (1) REFIDX, the refractive index at the point under consideration, and
- (2) SLOPE, the rate of change of refractive index with height at the point

Listing 1 gives the code used in ATMOS1, and may be used as an example to generate code for any other refractive index profile.

### 3.3 Examples of range-height-angle charts

A few examples of the charts that can be generated by this software are included to show the variation in shape of the charts with different values of the input parameters that might be expected when using this software. The refractive index profile described in ATMOS1 was used for all these charts. Figure 6 shows a typical chart with the source on the surface of the Earth, and the maximum range and height such that the ray passing through the intersection of the range and height boundaries subtends a considerable angle at the source. The second chart, figure 7, shows the output for an elevated source with a larger range limit. In this chart, the parameters are such that the tangent ray to the Earth's surface lies intersects the maximum height boundary before the maximum range is reached. As a consequence of this, the chart does not have a vertical range boundary. Figure 8 shows an example with a larger maximum range and maximum height, in which the tangent ray extends considerably below the origin of the chart. Charts such as this one provide the greatest difficulty in the estimation of suitable scale factors for the axes so that the resulting chart completely occupies the output page. The final example (figure 9), which is an expanded portion of figure 8, shows the increased density of rays that the software includes near the zenith when the scale factors are appropriate.

For extreme values of the input parameters, in particular for small maximum heights in comparison with the maximum range, the region near the horizontal ray will occupy most of

the chart, and consequently there will be a limited number of points from which to construct the range and height curves. In such cases the software will need to be modified to provide a greater density of rays between say  $2^\circ$  and the tangent ray. The statements requiring modification are in the DO statement controlling the angular increments (see Listing 2) within the procedure 'JLW.RAYTRACE.PLI(MAIN3)'. There are many possible ways in which these statements could be modified depending upon the specific requirements. Where the critical angles are known, direct replacement of appropriate sections of the DO specification with actual angular limits would suffice, and would be the easiest to implement.

#### 4. CONCLUSIONS

This report has described the physical principles behind a computer program for the generation of range-height-angle charts which provide an indication of the propagation paths of rays launched from a radar. The examples given to illustrate the use of the program have assumed a NBS single exponential refractive index profile, though in principle this program will operate with any refractive index profile that does not result in ducting of the electromagnetic rays. It is anticipated that minor refinements will be incorporated in the software from time to time, to improve the quality of output, for example, but no further major developments are proposed. The package as it stands is a useful product for quick guidance when radar coverage questions arise.

#### ACKNOWLEDGEMENTS

The contribution of Mr Tim Miller in developing the user interface is gratefully acknowledged.

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|----|--------------------------------|---|
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| 5  | Bean, B.R. and<br>Thayer, G.D. | "CRPL Exponential Reference Atmosphere".<br>National Bureau of Standards Monograph 4, October 1959      |

```

ATMOS1: PROCEDURE (HEIGHT,ALPHAR,REFIDX,SLOPE);

/* This subroutine is used to determine the refractive index, and */
/* the slope of the refractive index at the specified height HEIGHT */
/* of the refractive index profile specified in this algorithm. */
/* The parameter ALPHAR has no effect except at a discontinuity of */
/* the refractive index. ALPHAR > 0 causes routine to select */
/* refractive index approaching HEIGHT from above, < 0 from below */
/* The first call to this routine, with the variable INIT set equal */
/* to 0 results in the specification the constants and */
/* discontinuities in refractive index profile. Subsequent calls */
/* will have INIT set equal to 1 and will not repeat this */
/* initialisation activity Note that the Earth's surface is treated */
/* as a discontinuity in this software so there will always be one */
/* discontinuity. The refractive index profile specified here is */
/* the standard single exponential profile with no additional */
/* discontinuities. */

DECLARE (HEIGHT,ALPHAR,REFIDX,SLOPE) DEC FLOAT(16);
DECLARE (NS,Z) DEC FLOAT(16) STATIC,
        INIT BIT(1) INIT('0'B) STATIC;
DECLARE (DSCHGT(100) DEC FLOAT(16),
        NUMDSC BIN FIXED(31)) EXTERNAL STATIC;

/* test INIT to determine if this is first call to subroutine */
IF INIT='0'B THEN
DO,

/* specify constants for calculating refractive index */
NS = 313.0E-6;
Z = 7000.0E0;

/* specify discontinuities in refractive index profile */
NUMDSC = 1;
DSCHGT(1) = 0.0E0;
INIT = '1'B;

END;

/* calculate refractive index */
REFIDX = 1.0E0 + NS*EXP(-HEIGHT/Z);

/* calculate slope of refractive index */
SLOPE = -NS*EXP(-HEIGHT/Z)/Z;

END ATMOS1;

```

Listing 1 Sample Refractive Index Procedure (ATMOS1)

```
DO ANG = START1 TO END1 BY INTV1,  
    END1-1.0 TO MAX(UCANG,10.00) BY -1.00,  
    MAX(UCANG,10.00)-0.50 TO MAX(UCANG,5.0) BY -0.50,  
    MAX(UCANG,5.0)-0.10 TO 0.00 BY -0.10,  
    -0.02      TO TANANG BY -0.02,  
    TANANG-0.1 TO LCANG  BY -0.10,  
    LCANG-1.0  TO -10.0  BY -1.00,  
    START2 TO END2 BY INTV2;
```

In the above listing

- (1) UCANG corresponds to  $\rho$  in section 2.4
- (2) TANANG corresponds to  $\beta$  in section 2.4
- (3) LCANG corresponds to  $\gamma$  in section 2.4

Listing 2 DO Loop Parameter Specification

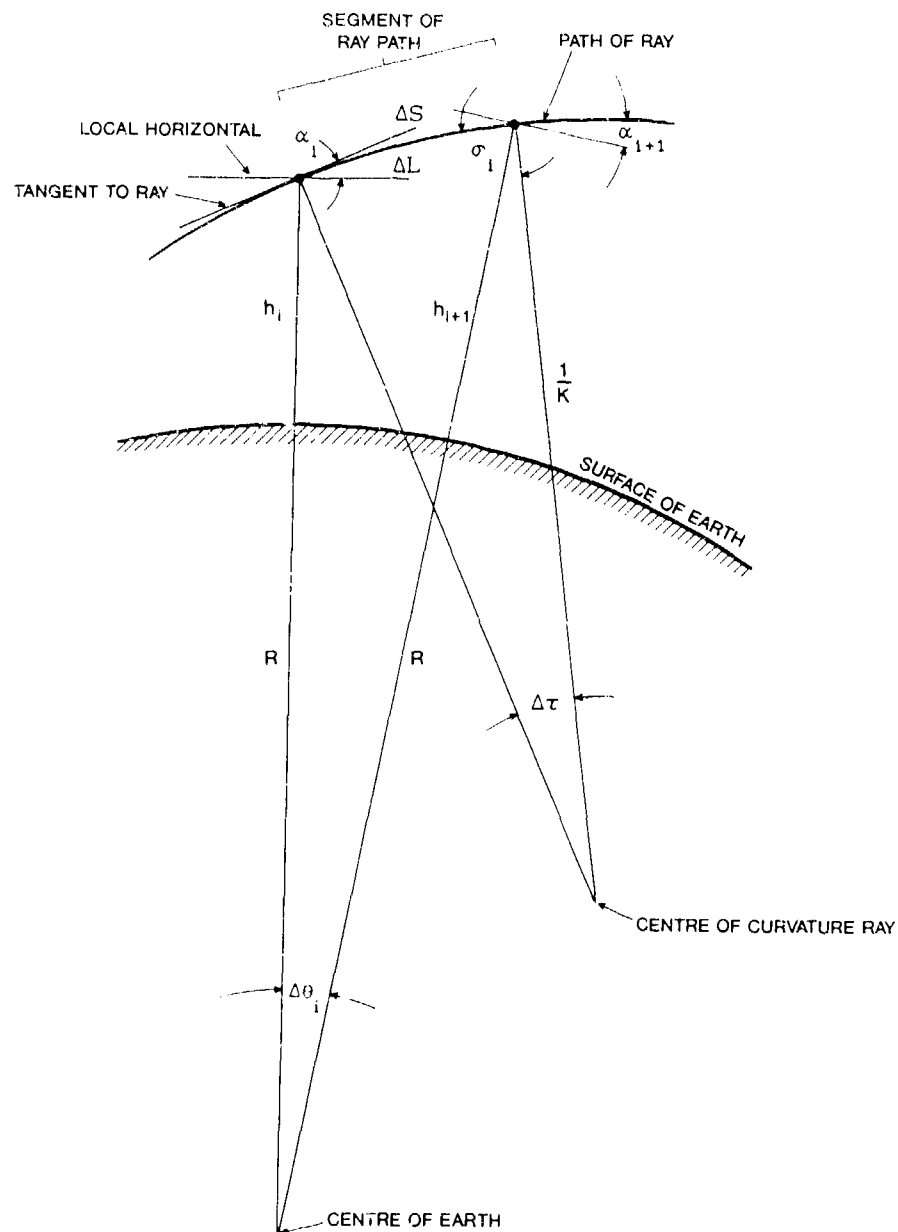


Figure 1 Ray path geometry

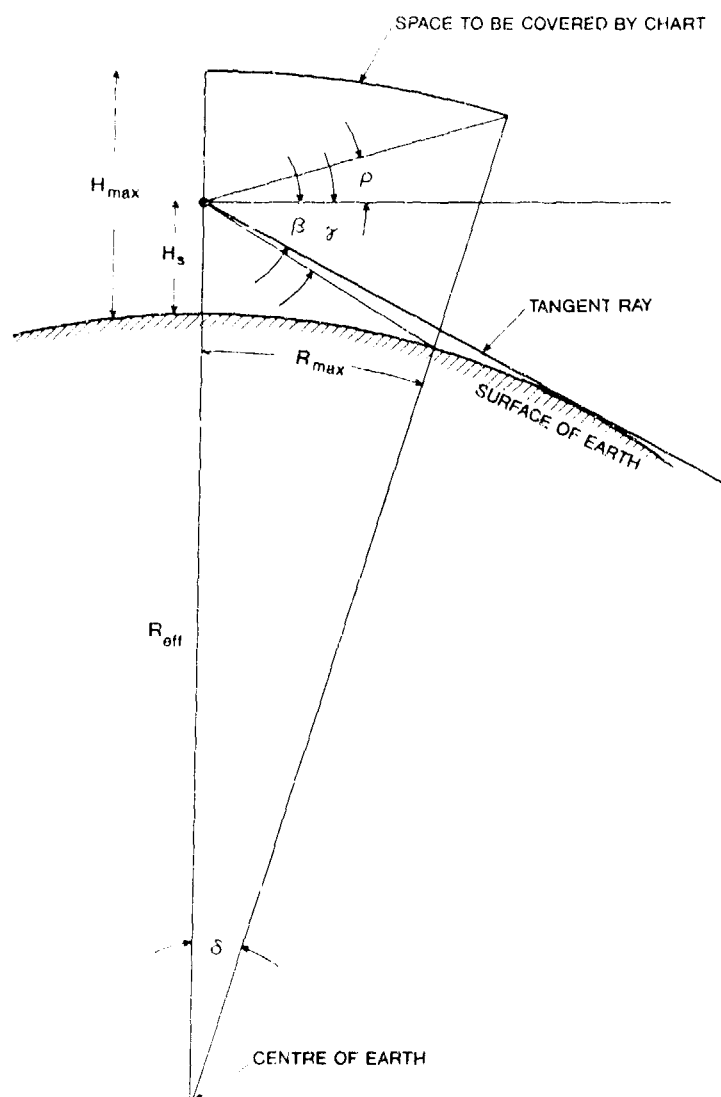
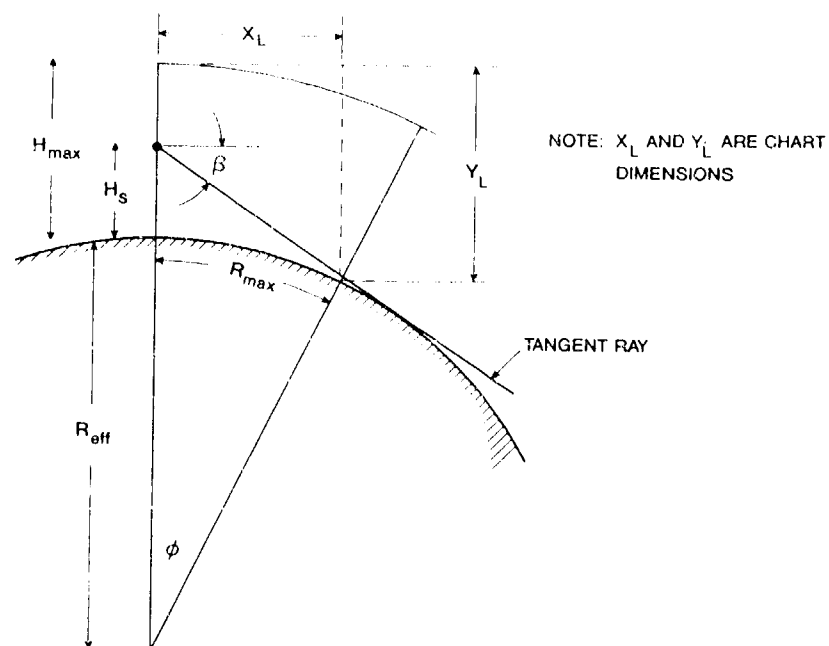
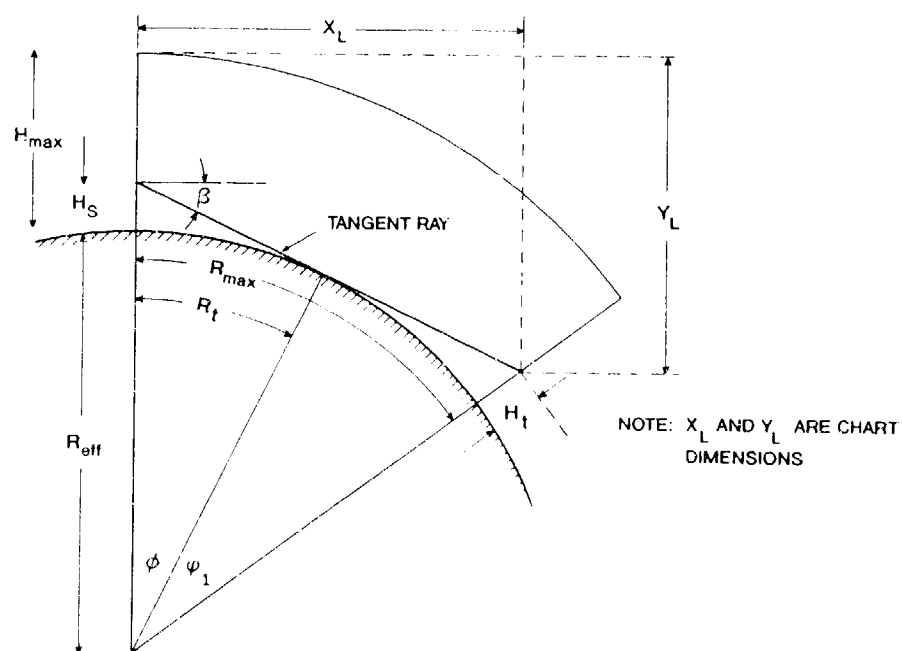


Figure 2 Launch angles to range and height boundary points

Figure 3(a) Chart geometry for  $R_{\max}$  within the radar horizonFigure 3(b) Chart geometry for  $R_{\max}$  beyond the radar horizon

----- RAYTRACE SELECTION PANEL -----

OPTION ===>

- 1 TRACE RAYS FROM A POINT FOR A RANGE OF LAUNCH ANGLES
- 2 TRACE RAYS BETWEEN TWO POINTS
- 3 PLOT RANGE HEIGHT CHARTS
- 4 PLOT PROPAGATION LOSS VERSUS HEIGHT

USE HELP (PF1) FOR EXPLANATION OF INPUT, PRESS ENTER TO CONTINUE  
END (PF3) TO TERMINATE RAYTRACING PACKAGE

Figure 4 Raytrace selection menu

----- RANGE - HEIGHT CHART PARAMETERS -----

SOURCE DATA

ANTENNA HEIGHT ===> (KFT)

REGION FOR RAY TRACING

MAXIMUM HEIGHT ===> (KFT)

MAXIMUM RANGE ===> (NM)

RANGE AND HEIGHT INTERVALS

HEIGHT INTERVAL ===> (KFT)

RANGE INTERVAL ===> (NM)

SPECIFICATION OF ATMOSPHERIC PROFILE ROUTINE

ATMOSPHERIC PROFILE ===>

SPECIFICATION OF PROGRAM OUTPUT REQUIREMENTS

GDDM VDU PLOT ===> (YES OR NO)

HP 9872 PLOTTER ===> (YES OR NO)

FILE MEMBER NAME ===>

USE HELP (PF1) FOR EXPLANATION OF INPUT, PRESS ENTER TO PROCESS DATA  
END (PF3) TO RETURN TO MENU

Figure 5 Chart parameter specification panel

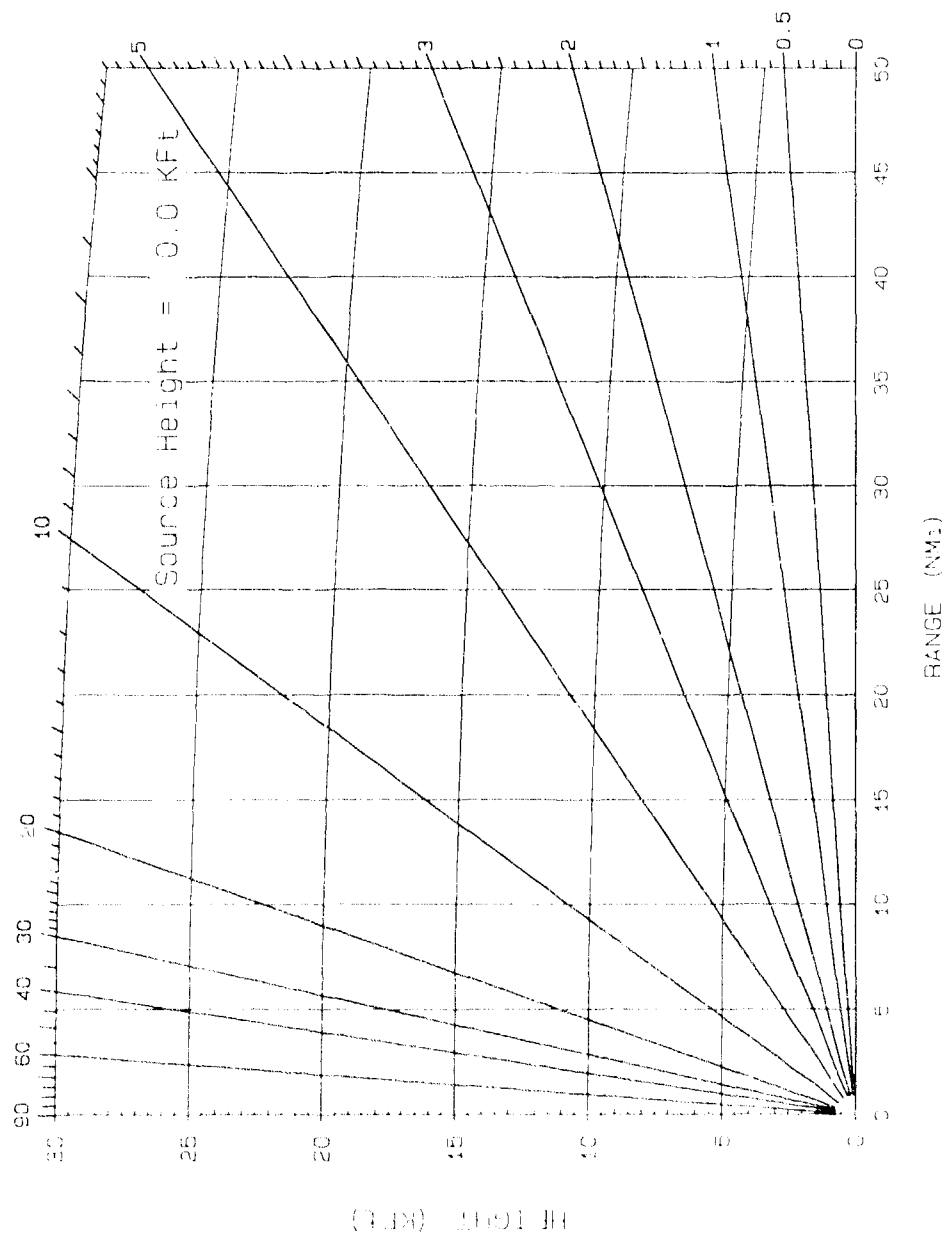


Figure 6 Sample range-height-angle chart

Source height = 0.3 Kft

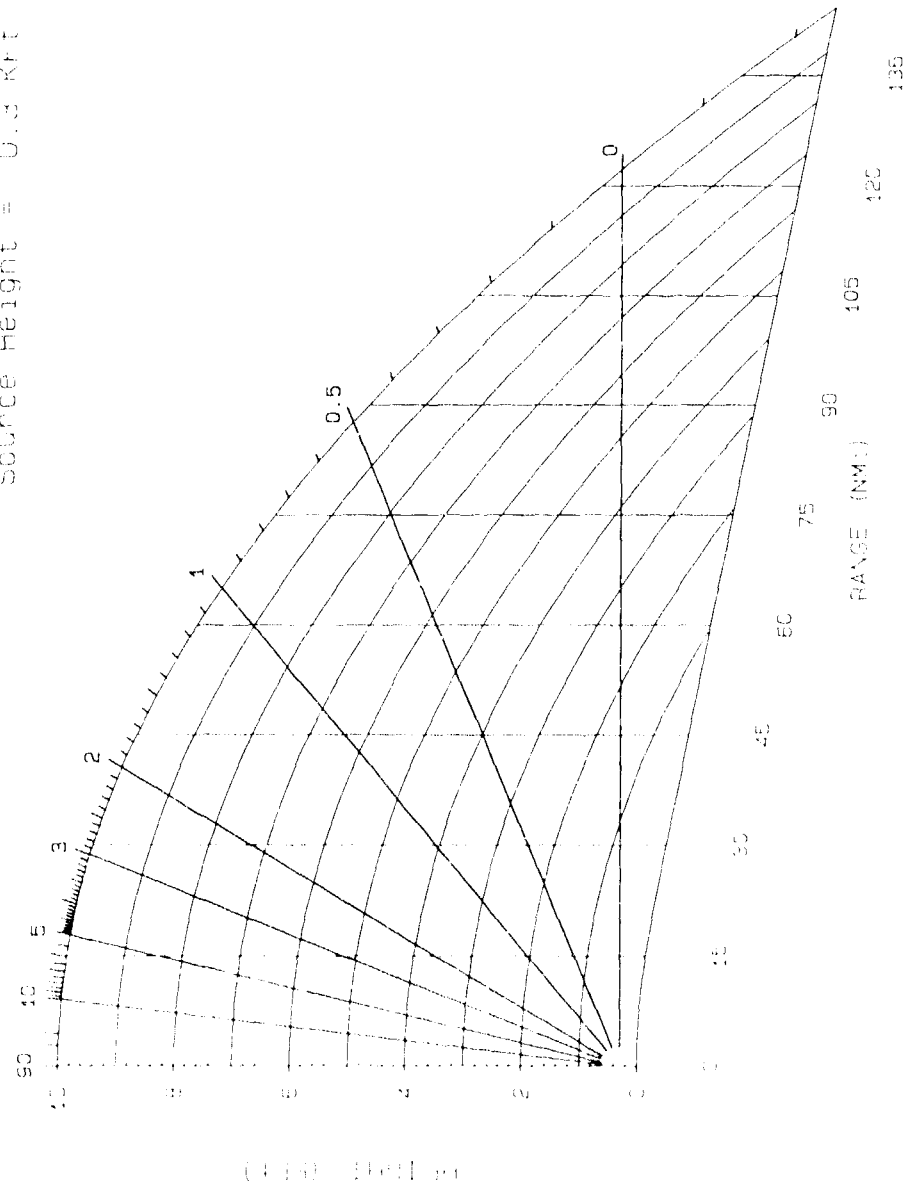
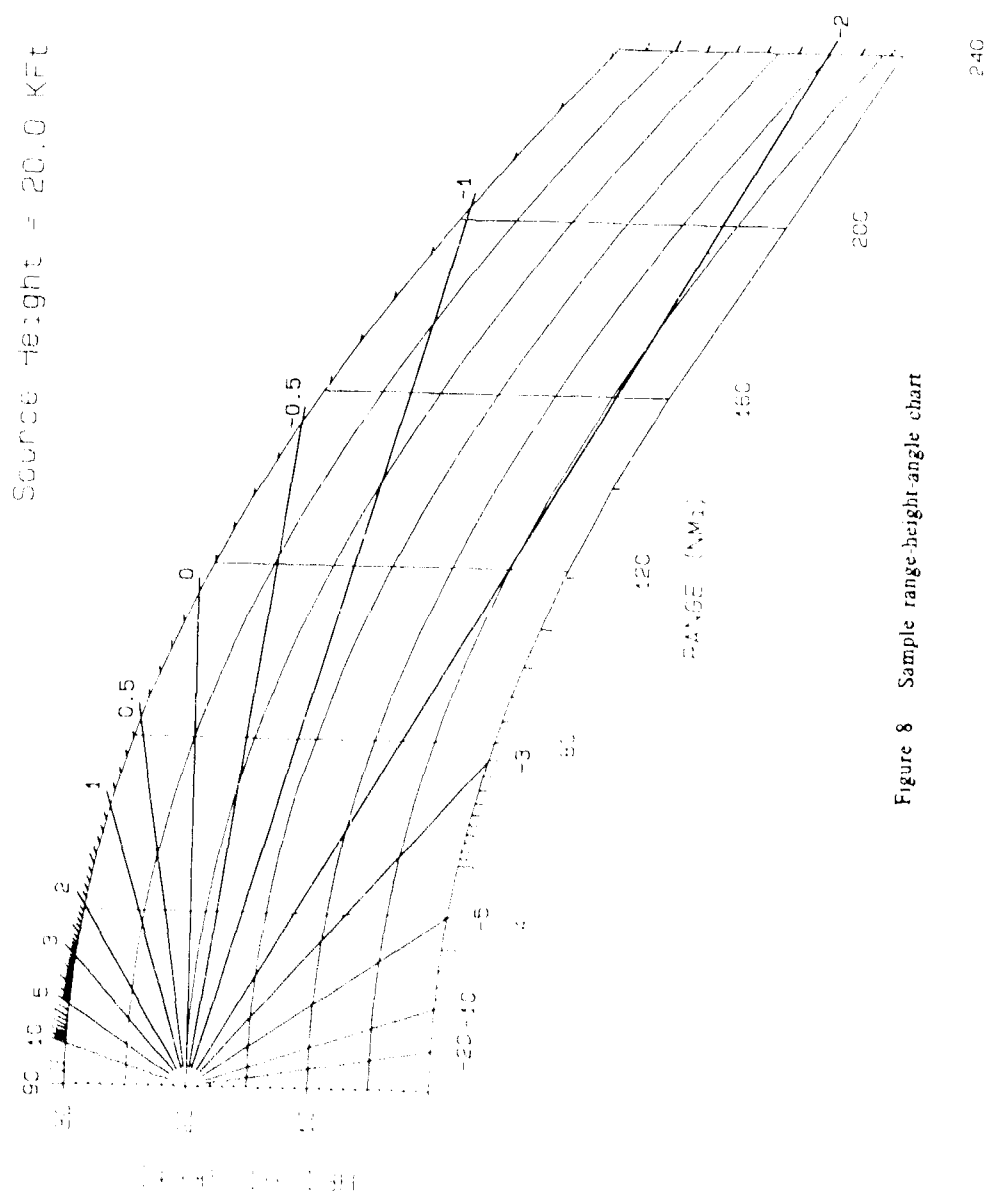


Figure 7 Sample range-height-angle chart



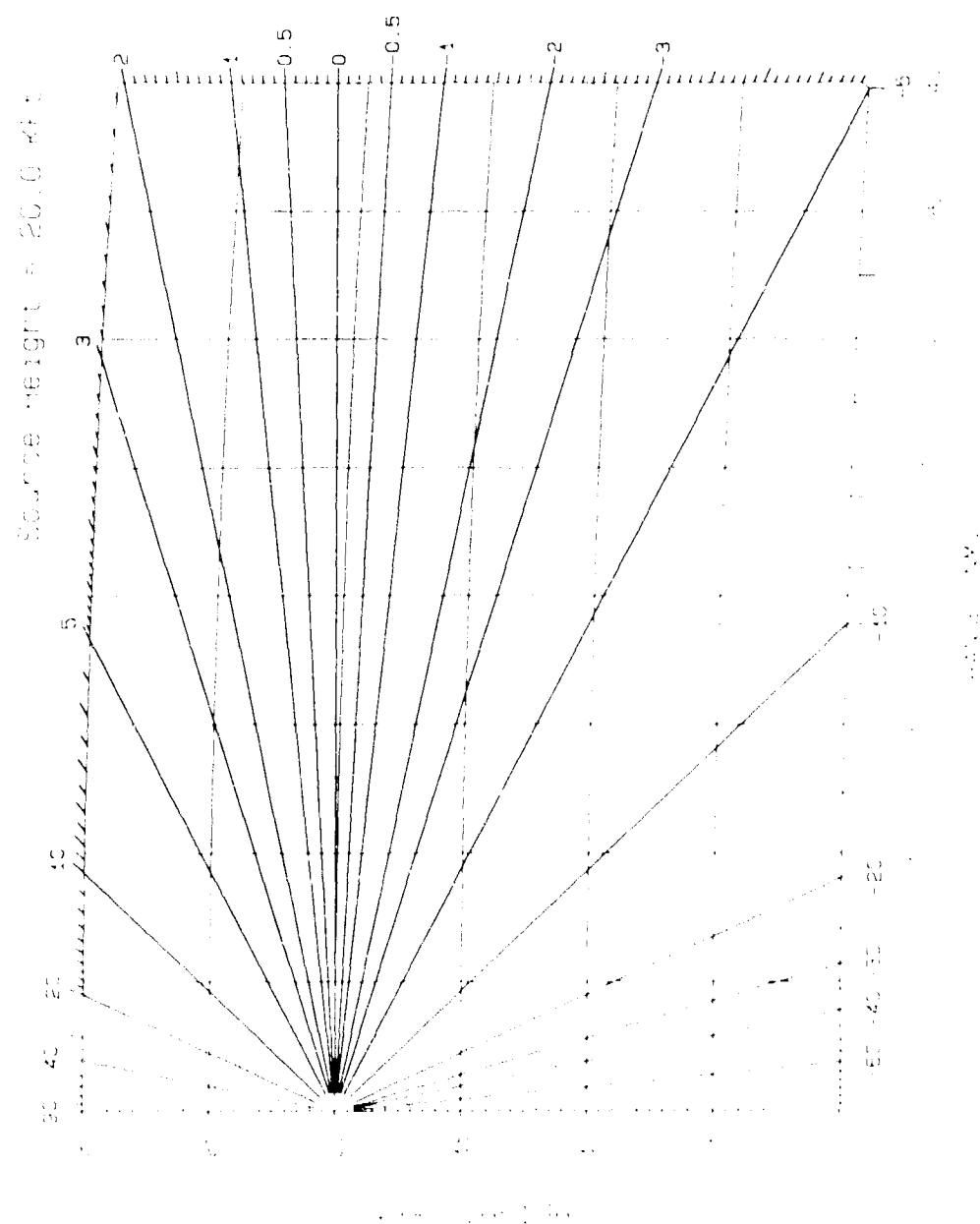


Figure 9 Sample range height angle chart

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17 SUMMARY OR ABSTRACT

(if this is security classified, the announcement of this report will be similarly classified)

This memorandum discusses a technique for the computer generation of range-height-angle coverage charts for radars of arbitrary height. Such charts are useful to provide a qualitative assessment of propagation paths between a radar and an arbitrarily positioned target.